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DIESEL ENGINE VIBRATION: DIAGNOSIS WITH A LASER

N.A. Halliwell, L. Pullen and J. Baker

Institute of Sound and Vibration Research, University of Southampton, Southampton, SO9 5NH

INTRODUCTION

Since the advent of the laser, optical metrology has found a much wider use in engineering and is now providing accurate experimental data which in many cases was hitherto thought unobtainable. This paper explains how a laser can be used in a simple optical geometry to measure normal surface and crankshaft torsional vibration velocities. Vibration characteristics of engines make them substantial 'velocity sources' over the frequency range of interest and consequently many of the sophistications included in commercially available system packages are unnecessary and can be avoided. The two vibrometer systems suggested are simple to construct, robust, inexpensive and do not require optical expertise for successful operation. Normal surface velocities (as measured by an accelerometer) are measured by an on-axis system which is fully portable and capable of hand-held use whilst the torsional velocity system can be tripod mounted. Both systems have been developed in the Laser Laboratory at I.S.V.R. and successfully used in the Engine Test Cells of the Automotive Engineering Group.

THE LASER VIBROMETER

With respect to on-axis vibration, there is a real need for a fully portable hand-held instrument which can take quick and accurate non-contact measurements of the normal surface velocities of an engine and thus eliminate the time consuming work of many accelerometer fittings, as well as offering the capability of successful measurement where surface contact is not practical. The optical geometry used is that proposed by Halliwell |1| in which the reference and collection arms of the anemometer have been folded with mirrors to form a compact unit as shown in Figure 1. The beam from a 2 mW H-Ne laser is divided by a beamsplitter and one beam (the reference beam) is incident on the retro-reflective surface of a rotating disc whilst the other is

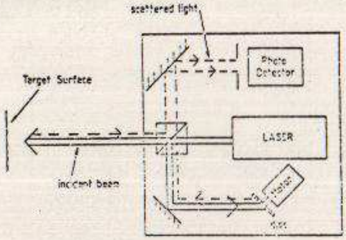
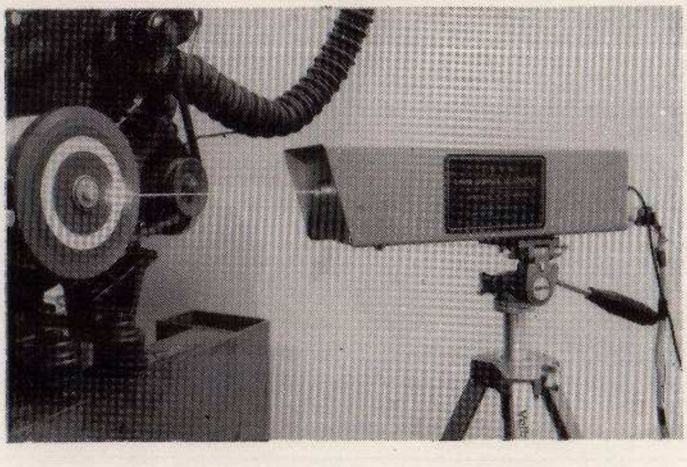


Figure 1.

incident on the target surface. Light backscattered from the disc undergoes a Doppler shift which is constant due to the constant speed of rotation and heterodynes with light collected in backscatter from the surface. In this way the two objectives' speckle patterns produced by disc and target surface are automatically mixed and collected over the solid angle subtended by the detector area. The constant Doppler frequency from the disc acts as a 'carrier' frequency which is modulated by the target surface movement. A simplified Doppler signal processor provides a time-resolved voltage analogue of surface velocity. For a fuller description of the physics of operation, readers should refer to reference |1|. The whole instrument can be installed in a box which is typically 35 × 12 × 12 cm, thus permitting hand-held use. A photograph of the completed instrument is shown in Plate 1.

The laser vibrometer is not only a considerable time-saver in test cell use but is also convenient for a rapid diagnosis of engine health. Big end and main bearing faults can be recognised, together with injector problems. Figure 2 shows vibration velocity spectra taken on an injector of a 16-cylinder marine diesel and clearly demonstrates the reduction in level produced by a reduction in fuel injection

Plate 1.



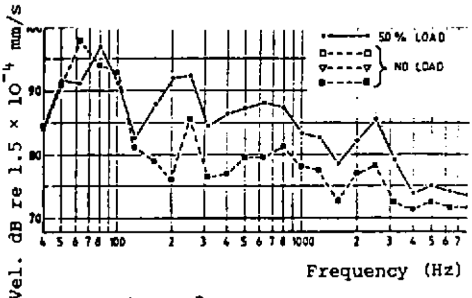


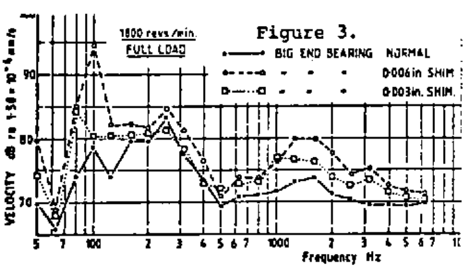
Figure 2.

quantity. In order to demonstrate the ability of the vibrometer to 'localise' faults, shims were placed in the big end bearing of No. 2 cylinder of a 6-cylinder diesel engine. Measurements taken on the crankcase opposite this cylinder are shown in Fig. 3 and demonstrate the increase in vibrational level produced. In order to ensure that changes in structure response levels were indeed due to increased bearing clearance, a further measurement was taken at a point towards the rear of the engine. It could be assumed that due to the damping characteristics of the engine structure a negligible effect on vibrational level should be produced and the results shown in Fig. 4 show this to be the case.

For a fuller description of health diagnosis with a laser vibrometer, readers should refer to reference [2]. A comparison of laser and accelerometer acquired data on a six-cylinder turbocharged diesel is shown in Fig. 5. Discrepancies above 5 kHz are due to the third octave filtering used.

THE LASER TORSIONAL VIBROMETER

The optical geometry of the torsional vibrometer is shown in Fig. 6. With this arrangement the Doppler frequency (f_D) which modulates the output of the photodetector is given by $f_D = (2U \sin(\theta/2))/\lambda$,



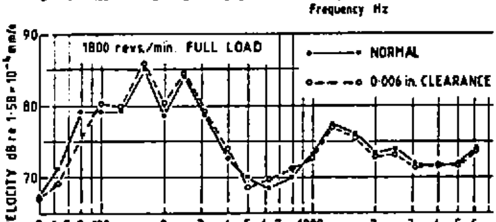
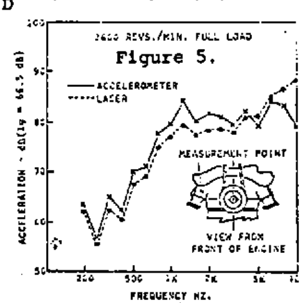
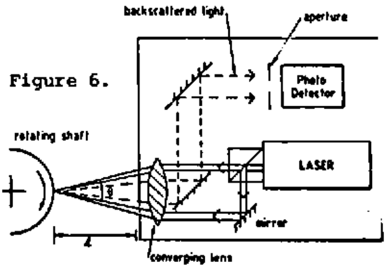


Figure 4.



where λ is the wavelength of the laser light [3]. The Doppler processor again provides a time resolved voltage analogue of f_D, i.e. the shaft tangential surface velocity U. The surface must be kept within the intersection region of the two laser beams which is $\simeq$ 0.5 mm in length, which means this instrument must be tripod mounted. Comparison of results taken with this system and those obtained from the more traditional 'slotted disc' method are shown in Figure 7.

Figure 6.



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[1] N.A. Halliwell, "Laser Doppler Measurement of vibrating surfaces: a portable instrument", Journal of Sound and Vibration 62(2), 312-315 (1979).

[2] N.A. Halliwell, H.L. Pullen and J. Baker, "Diesel engine health: laser diagnostics", I.S.V.R. Memorandum No. 637, University of Southampton (1983). To be published S.A.E. September Conference, Milwaukee, U.S.A.

[3] F. Durst, A. Melling and J.H. Whitelaw, "Principles and Practice of Laser-Doppler Anemometry", Academic Press, London (1976).

Figure 7.